Oceans 2003
San Diego, CA

Energy R&D At The California Energy Commission With Comments On The Use of Ocean Resources

Terry Surles, David Navarro

California Energy Commission

Christopher Guay

Lawrence Berkeley National Laboratory

September 25, 2003

Outline

- PIER Program Overview
- Oceans and energy
  - Tidal Energy
  - Ocean Thermal Energy Conversion (OTEC)
  - Carbon Sequestration
  - Wave Energy
- Summary of CEC Wave Resources Report

California has Established a $62M/yr
Public Interest Energy Research Program (PIER)

<u>Quality</u>:
Reliable and Available

<u>Economy</u>:
Affordable Solutions

<u>Environment</u>:
Protect and Enhance

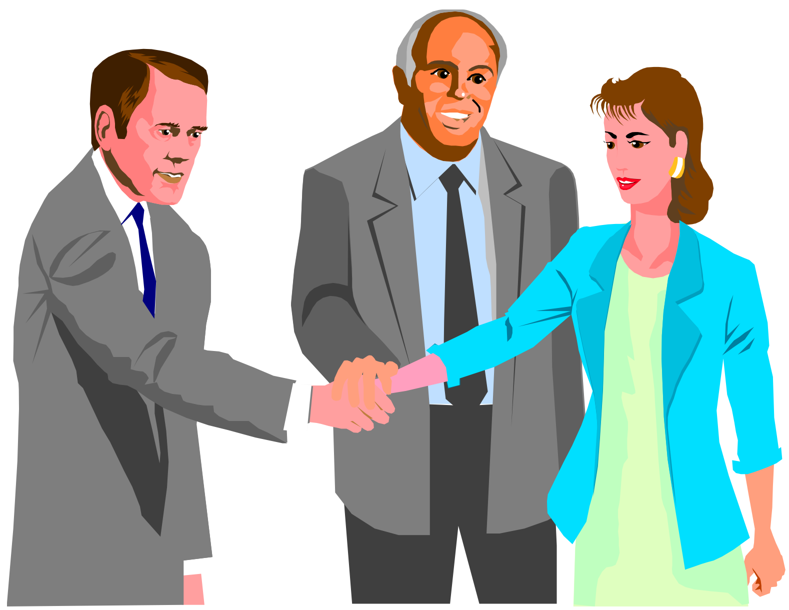
Legislative History for Starting PIER Program

- **AB 1890 (September 1996) established a new policy (Public Goods Charge) to support**
  - **Public interest energy research (PIER) ($62.5M)**
  - **Renewable market support (CEC) ($135M)**
  - **Energy efficiency market support (CPUC) ($245M)**
- **SB 90 (November 1997) created the Public Interest Energy Research Trust Fund**
- **AB 995/SB 1194 authorized program extension to 2011**

Vision Statement

The future electrical system of California will provide a clean, abundant and affordable supply tailored to the needs of "smart", efficient customers and will be the best in the nation.

Tailored, clean, abundant, affordable supply



Smart, efficient customers

PIER Mission Has Remained Unchanged Since 1998

The Mission of the PIER program is to conduct public interest energy research that seeks to improve the quality of life for California's citizens by providing environmentally sound, safe, reliable and affordable energy services and products.

PIER Public Benefit Objectives were Modified in 2002 Using Multi-Attribute Decision Analysis

- Improve energy cost/value
- Improve environment, public health, and safety
- Improve electricity reliability/quality/sufficiency
- Provide greater consumer choice
- Develop near-term applications
- Address research gaps

PIER Must Have A Vision to Address Future Scenarios: Decentralization, Environment, and Choice

Regulated

Status Quo

- **New energy systems**
- **Same players**

Centralized

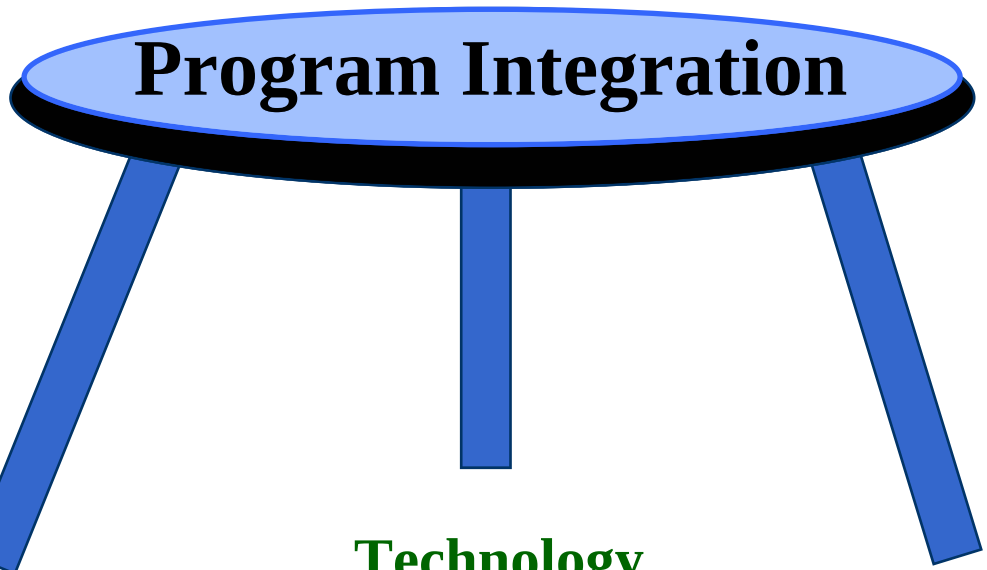
De-centralized and Clean

- **Same energy systems**
- **New players**

Supermarket of Choices

De-regulated

Attributes for Addressing State Issues

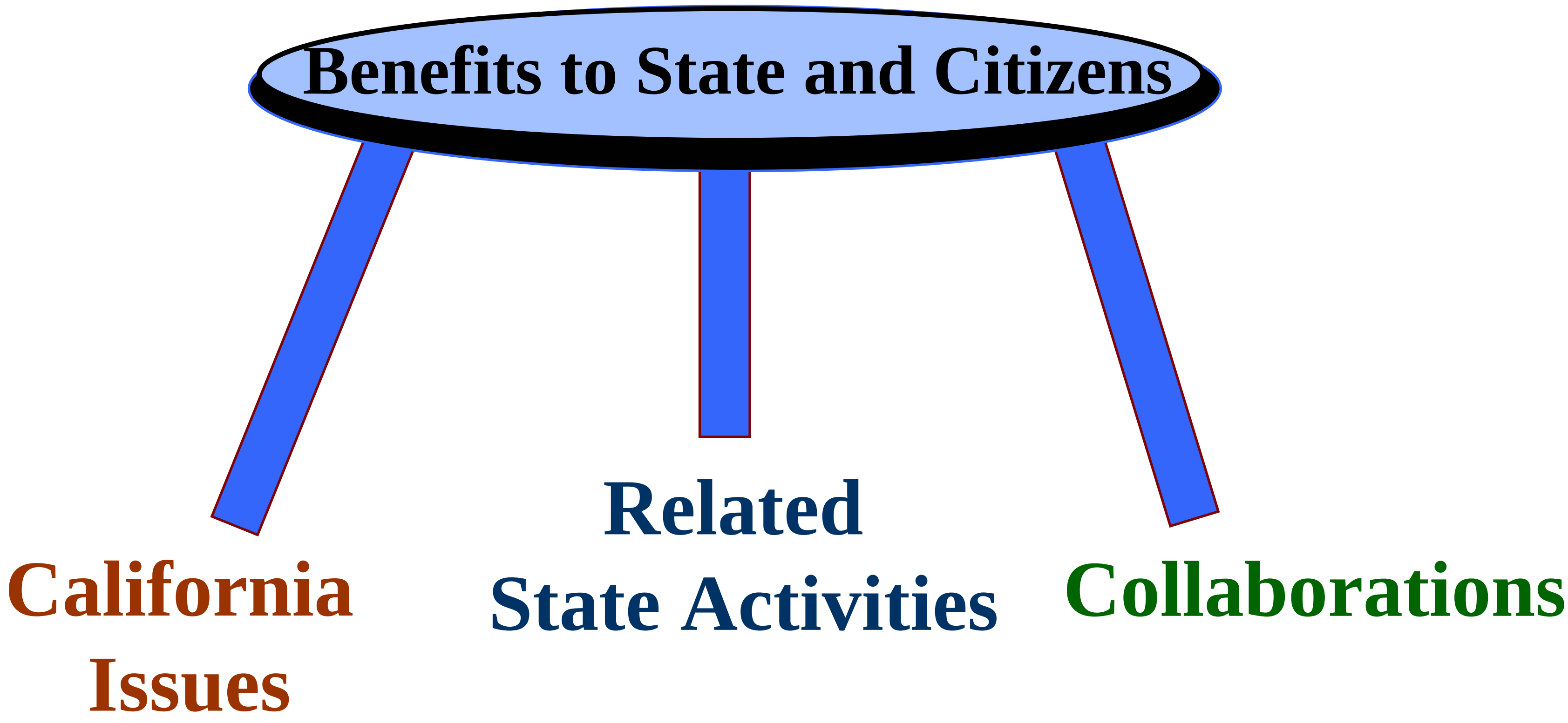


Balanced Technology Portfolio
- Temporal (stress near-term)
- Technology (end use, DER)

Technology Partnerships
- Universities
- Industry
- Federal
- State

Focus on California
- Specific to State needs

Policy and RD&D Must Be Linked in Order to Provide Benefits to the State



California Must be Prepared to Face the Same Issues as Others Must

- **Economics**
  - **Resource Competition**
  - **New technology market penetration**
  - **Life cycle analysis**
  - **State/Federal Laws**
- **Environment**
  - **Impact of new technologies**
  - **Climate change**
  - **Sustainable practices**
- **Security**
  - **Peak demand/demand response**
  - **Infrastructure interdependencies**

Energy Costs Fundamentally Affect our Overall Economy

PIER Program Should Tie Into, Where Possible, Synergistic State Regulatory, Incentive, and Subsidy Programs

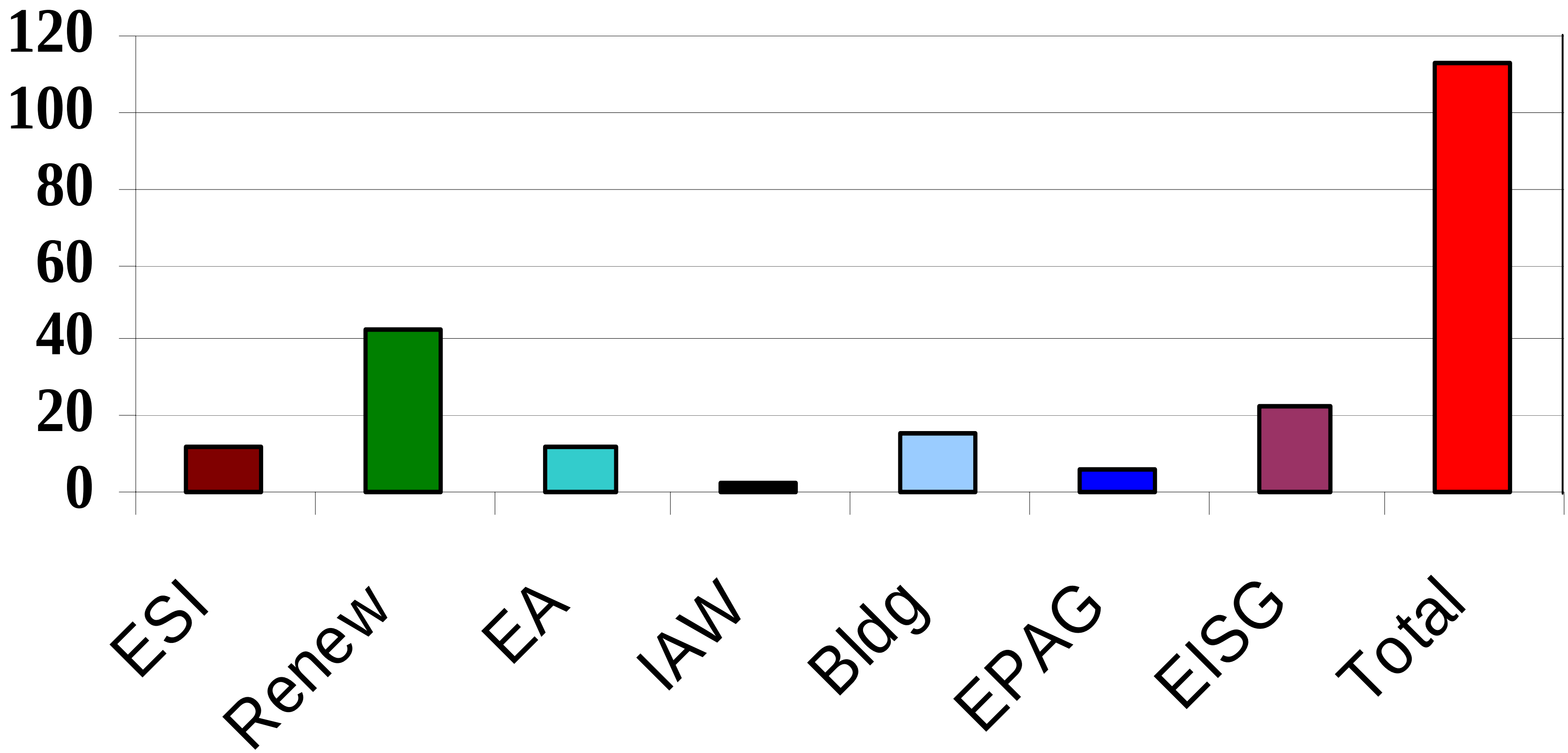
- Buildings – Titles 20 and 24
- Renewables – Renewable portfolio standard (RPS)
- Environmentally-Preferred Advanced Generation – 2007 ARB rules on distributed generation emissions
- Energy Systems Integration – CPUC/CEC initiatives in demand response/dynamic pricing, distributed energy resources, and transmission and distribution systems
- Environmental – Impacts/opportunities related to RPS, state initiatives (AB 1493) in climate change

Our Success is Coupled to the Successes of our Technology Partnerships

- Universities – UCOP, standard contract
- Industries – funding, obtaining co-funding, pushing deployment
- Federal – Departments of Energy, Commerce, Agriculture
- National Laboratories – LBNL, NREL, LLNL, ORNL, NETL, SNL, ANL
- State – ARB, CDF, DWR, DOGGR, CFA, CPA, CPUC, DGS

$ External Funding Into State

(in $ Millions)



Expectations Include the Development and Enhancement of Critical Relationships

- **Success in connecting with peers in DOE and other agencies**
  - **Collaborative funding**
  - **Reciprocity on review teams**
  - **Enhanced CEC visibility: Making a difference on a national level**
- **Maintaining ties with successful contractors**
  - **Stream of products to markets**
  - **Step-wise successes from research to deployment**
  - **On-going value to enhance intellectual critical mass**
- **Tying our programs to other state activities and regulations**
  - **Political strength of programs, i.e. ARB, CDF, DWR, SVMG**
  - **Linkage of R&D to implementation; i.e. CEC Efficiency, CEC Renewables, CPUC, ARB**
  - **Linkage to Regulations: SB 1771, SB 1298, CEQA, SB 1078, Title 24**

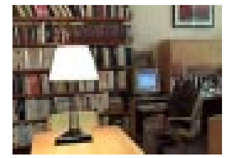
California Developed an Energy Action Plan in 2003

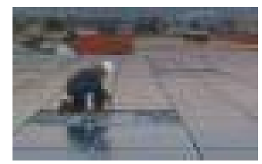
- Optimize energy conservation
- Accelerate renewable generation - 20% by 2010
- Ensure reliable electricity generation - peak demand reduction, new renewable goals
- Upgrade the transmission system
- Promote distributed generation - renewables, microturbines, fuel cells
- Ensure reliable natural gas

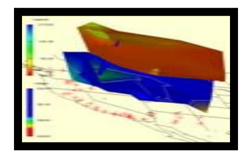
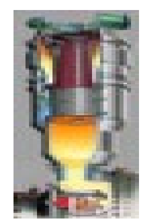
CEC/PIER is Already Providing a Stream of Products Consistent with the California Energy Action Plan (CEAP)

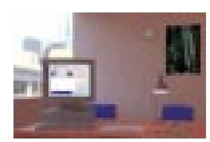
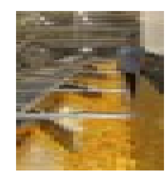
CEAP Goal	PIER Issue
Optimize efficiency, Reduce demand	Reduce per capita energy use
Ensure power supply meet RPS	Meet RPS
Upgrade T&D structure	T&D System must be reliable and congestion-free
Promote DG	Peak demand reduction Low emissions DG Reliable, affordable DG
Ensure reliable supply of NG	Meet marketplace needs

Products

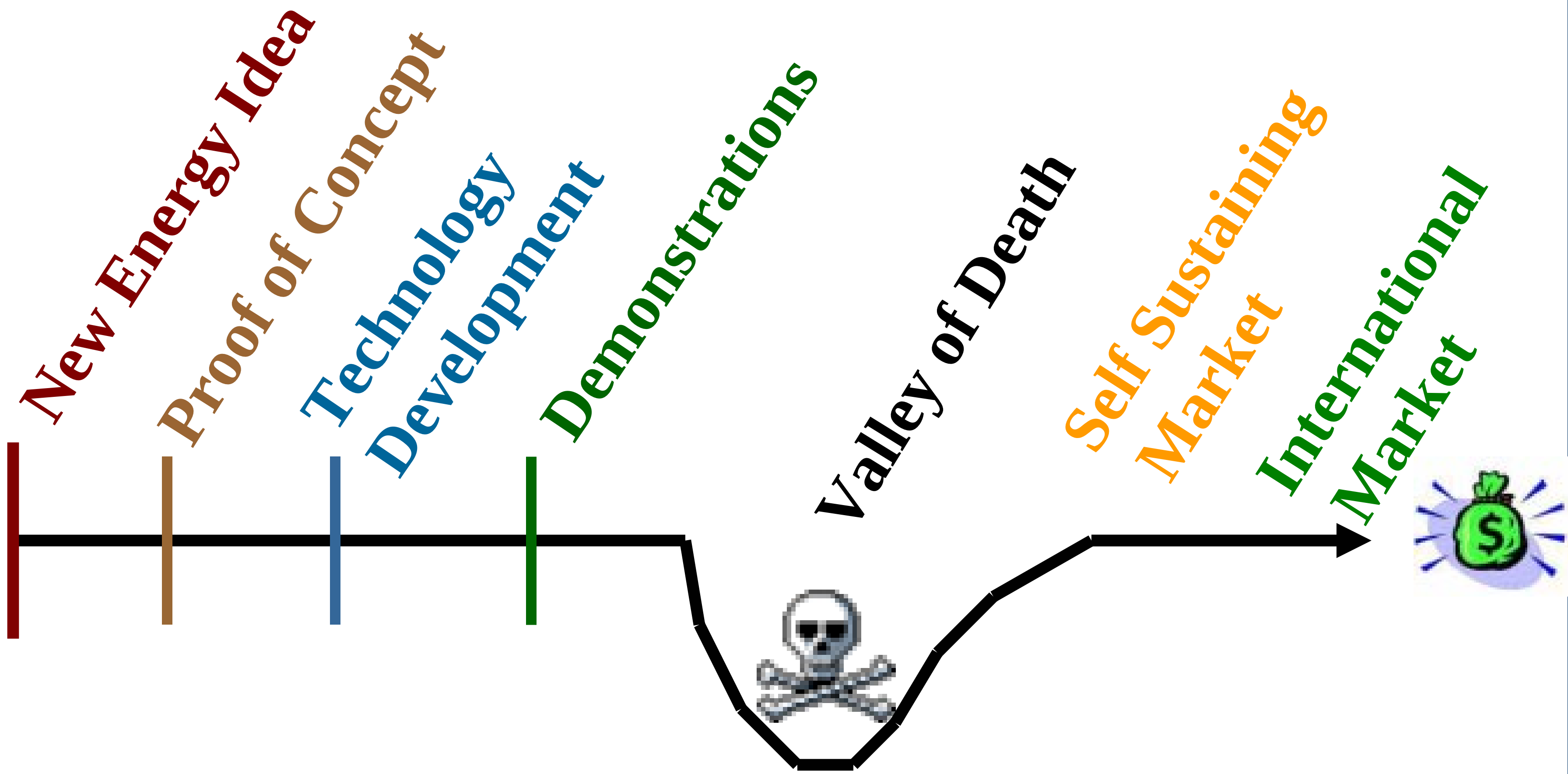




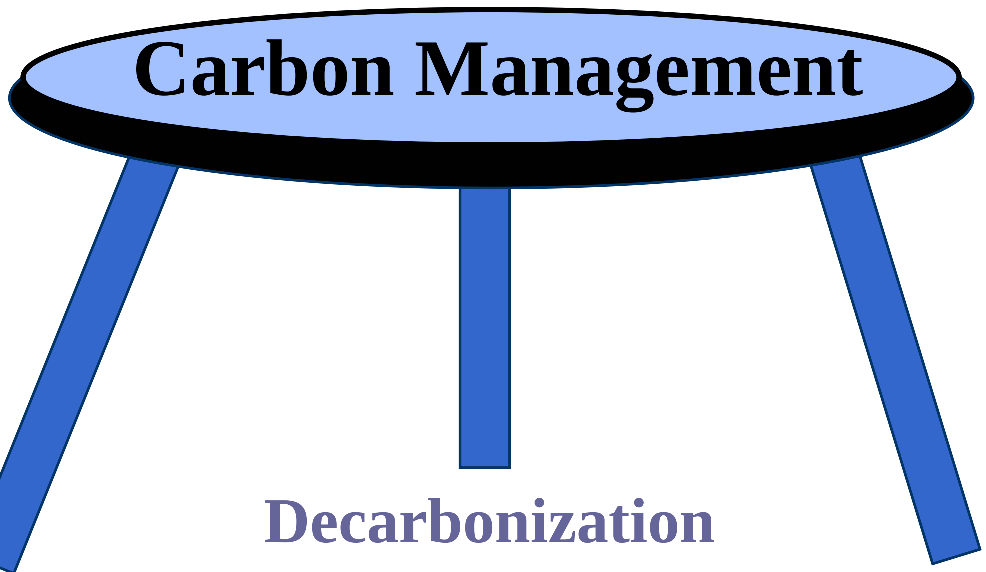




PIER is Attempting to Bridge the Valley of Death: NREL Growth Forum, Incubators, SB 1038



Carbon Management: An Approach for Integrated Energy Systems Management



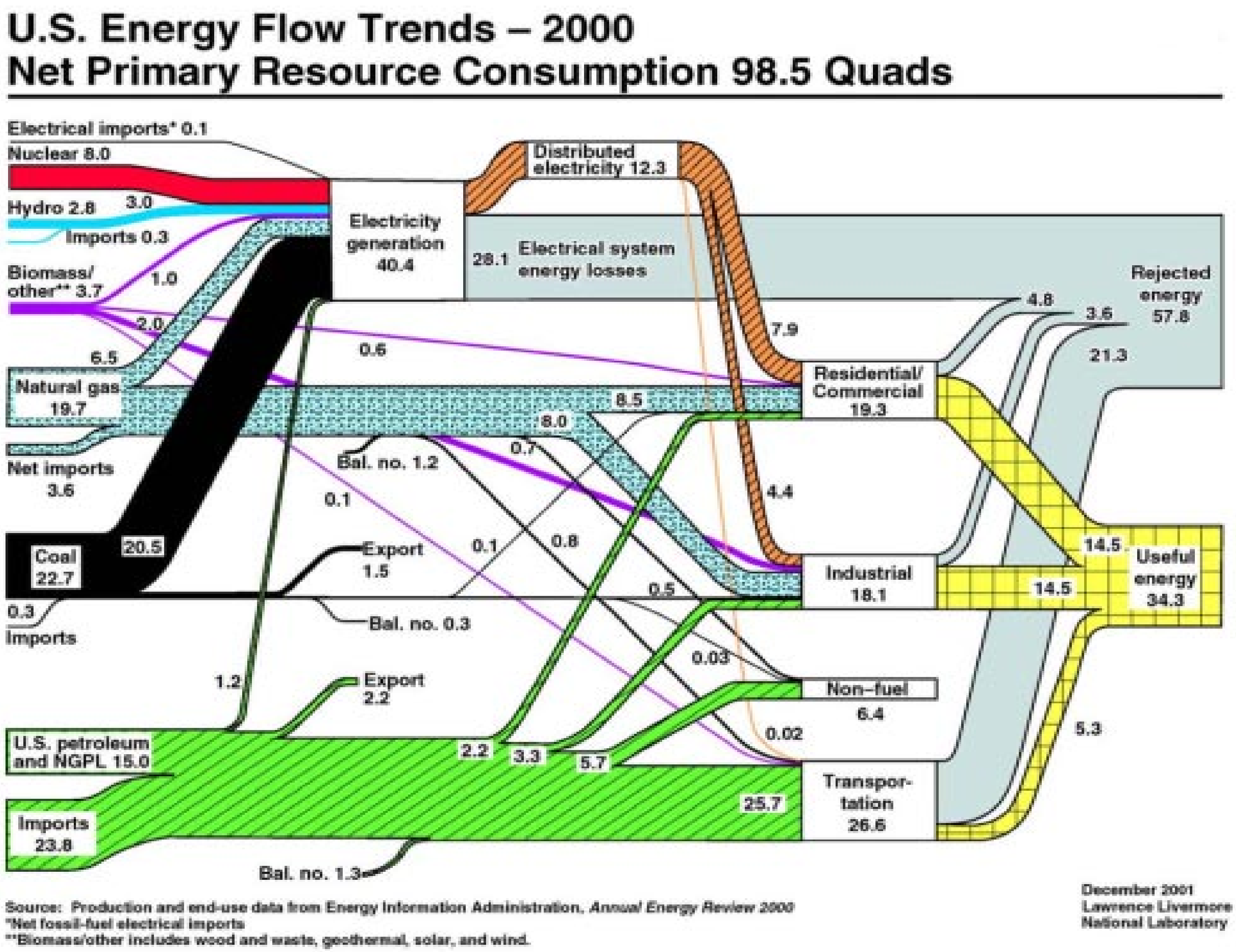
Decarbonization

- “clean energy”

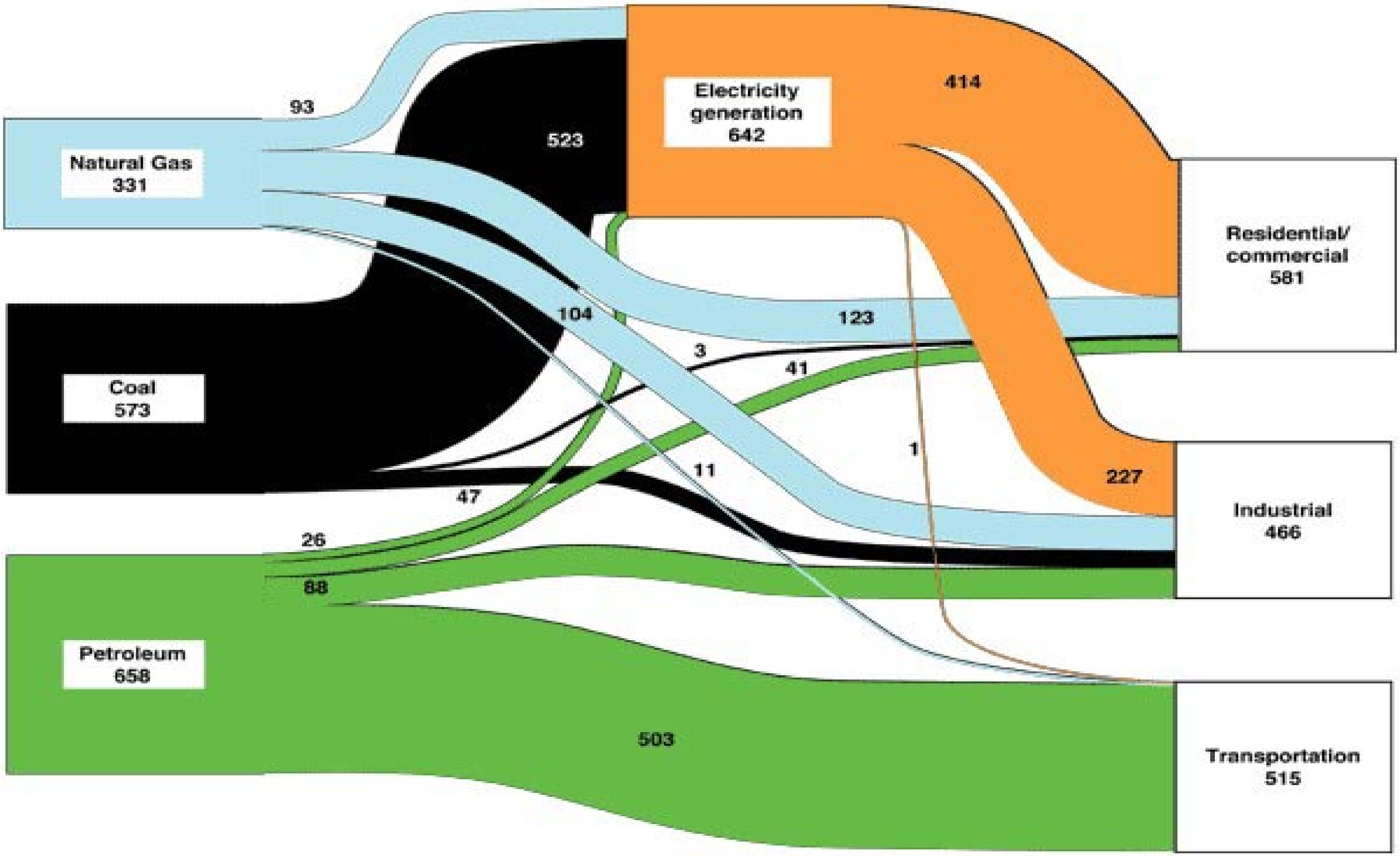
Efficiency

-operational
- DSM
- end use

Sequestration


U.S. Energy Flow Trends – 2000
Net Primary Resource Consumption 98.5 Quads
Electrical imports* 0.1
Nuclear 8.0
Hydro 2.8
3.0
Imports 0.3
Biomass/ other** 3.7
1.0
2.0
6.5
Natural gas 19.7
Net imports 3.6
Coal 22.7
20.5
0.3
Imports
U.S. petroleum and NGPL 15.0
Imports 23.8
Bal. no. 1.3
1.2
Export 2.2
Electricity generation 40.4
Distributed electricity 12.3
28.1
Electrical system energy losses
0.6
Bal. no. 1.2
0.1
Export 1.5
Bal. no. 0.3
0.1
0.8
0.7
8.0
8.5
0.5
0.03
0.02
2.2
3.3
5.7
25.7
7.9
4.4
Residential/ Commercial 19.3
Industrial 18.1
Non-fuel 6.4
Transportation 26.6
4.8
3.6
21.3
Rejected energy 57.8
14.5
14.5
Useful energy 34.3
5.3
Source: Production and end-use data from Energy Information Administration, Annual Energy Review 2000
*Net fossil-fuel electrical imports
**Biomass/other includes wood and waste, geothermal, solar, and wind.
December 2001
Lawrence Livermore National Laboratory

US 2000 carbon emissions from energy consumption — 1547* MtC



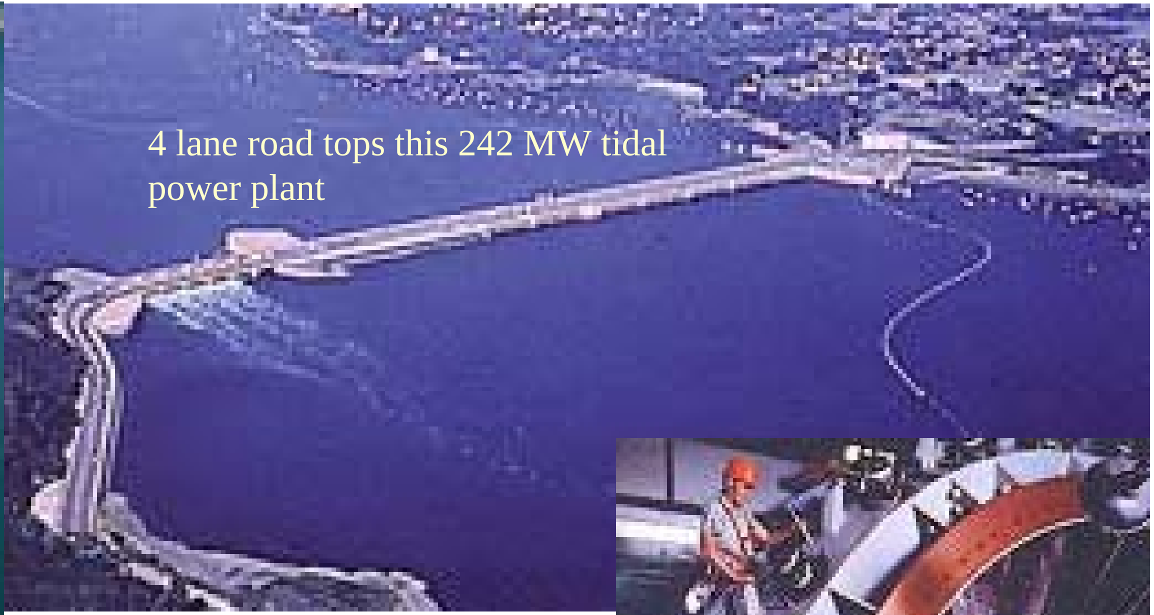
Source: Energy Information Administration
*Includes adjustments of 14 million metric tons of carbon from U.S. territories, less 28 MtC from bunker fuels

Lawrence Livermore National Laboratory, April 2002
http://en-env.llnl.gov/flow/

PIER Program Focus

- Renewable energy
- Environmentally-preferred advanced generation
- Residential and commercial buildings end-use energy efficiency
- Agricultural and industrial demand side technologies
- Energy-related environmental research and assessment
- Energy Systems Integration
- Energy Innovations Small Grants program (EISG)

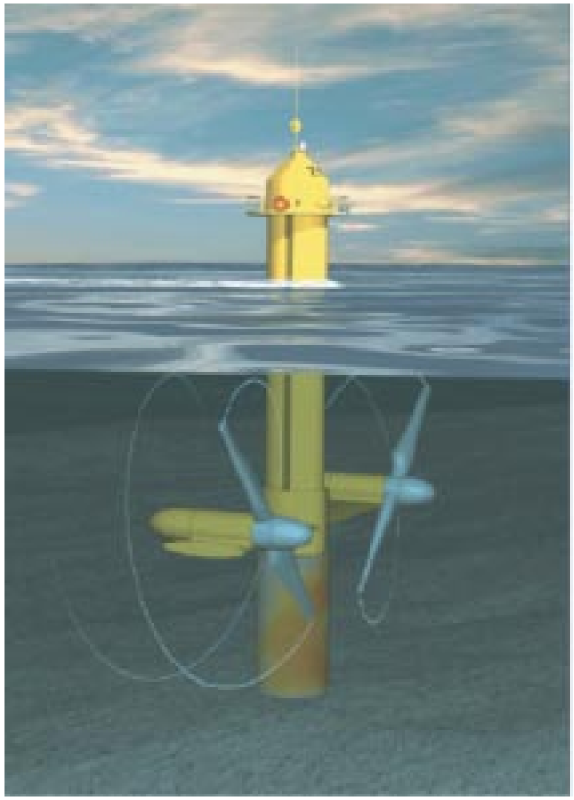
Tidal Energy: Impoundment/Turbines

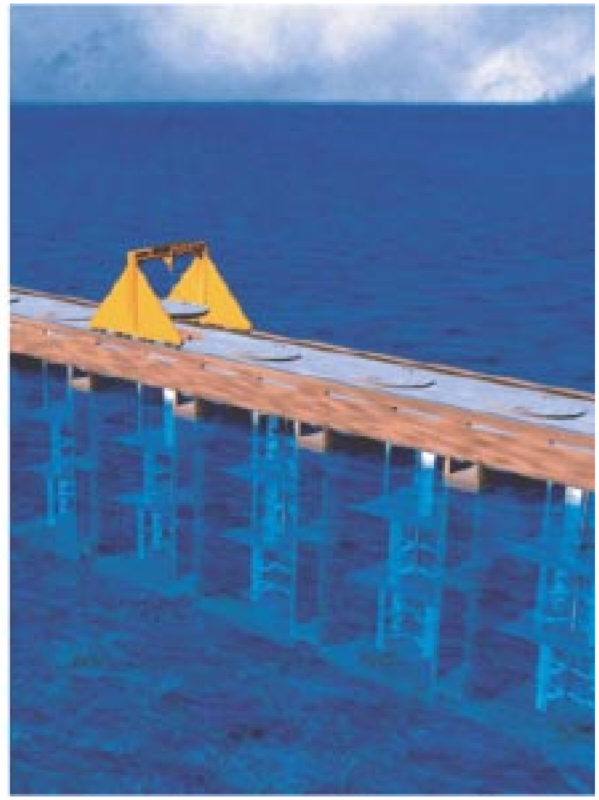


La Rance Estuary, France
242 MW
Operating Since 1967

Tidal Energy: Free-Flow Turbine Devices

Marine Current Turbines





Blue Energy Canada Tidal Fence

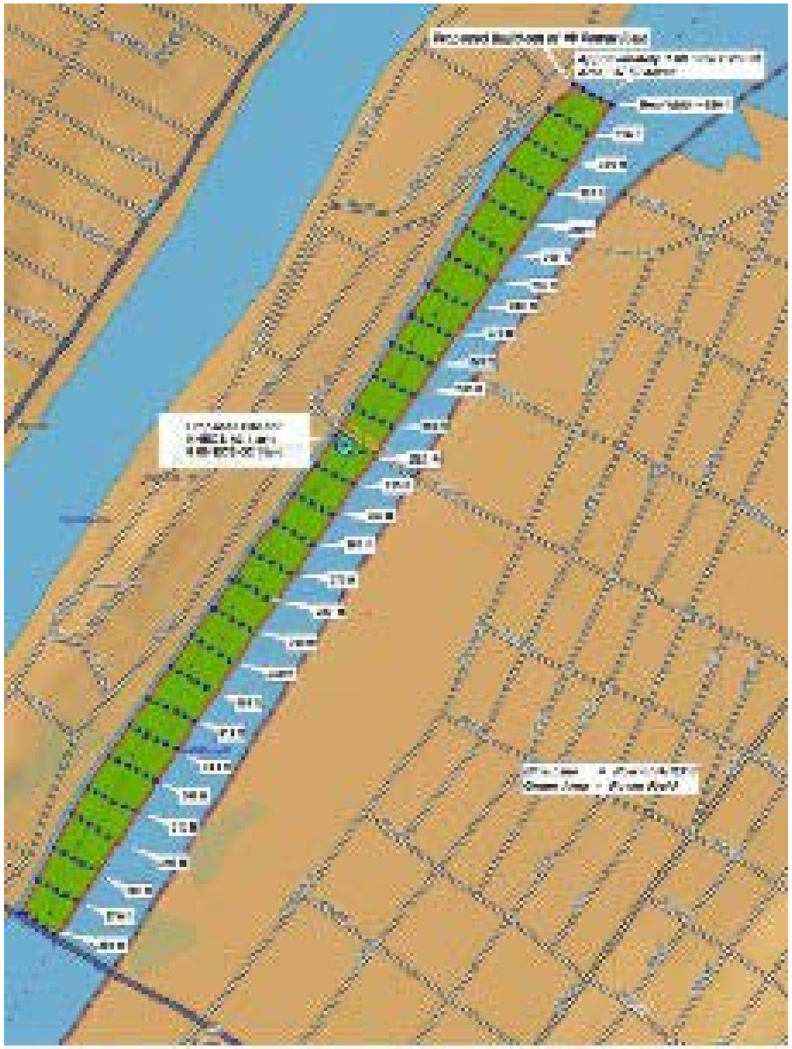
DRAWBACKS

- Require large areas of shallow water
- Obstruction of navigation
- Impact on fish and marine mammals
- Vulnerable to debris (deadheads, etc.)

Tidal Demonstration
East River, New York City

Verdant Power received funding from NYSERDA and other participating state, federal, and private organizations for a prototype demonstration. FERC has issued a preliminary permit for the prototype tidal project.

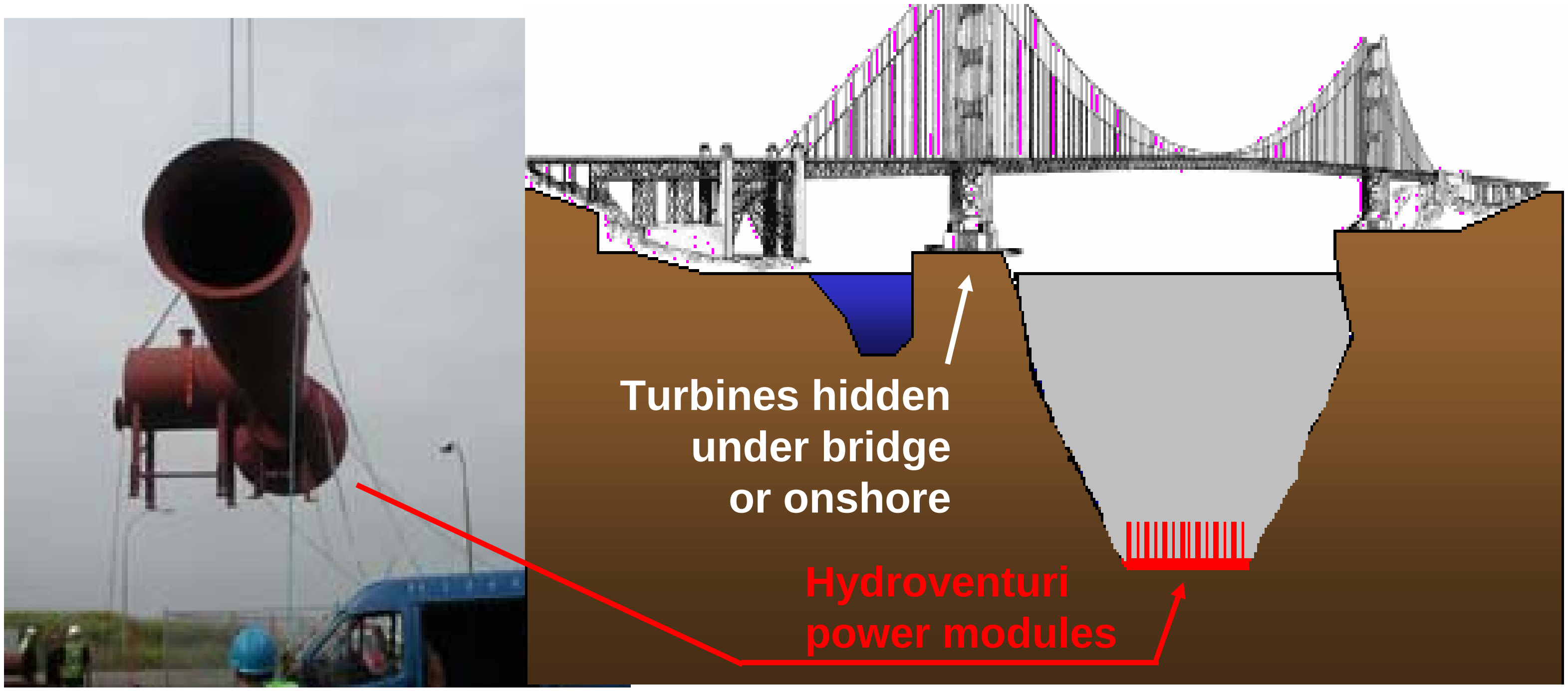
Tidal Demonstration
East River, New York City



The proposed East River turbine field, shown in green, will progress over 4 years, beginning in 2004. The 1 mile long by 270 feet wide and 30-40 feet deep tidal plant will ultimately provide 5-10 MW.

Verdant Power expects to complete this $20 million East River project, including power conditioning and grid connection, within four years. Subsequent sites are expected to be developed in less than one year.

Proposed San Francisco Tidal Project

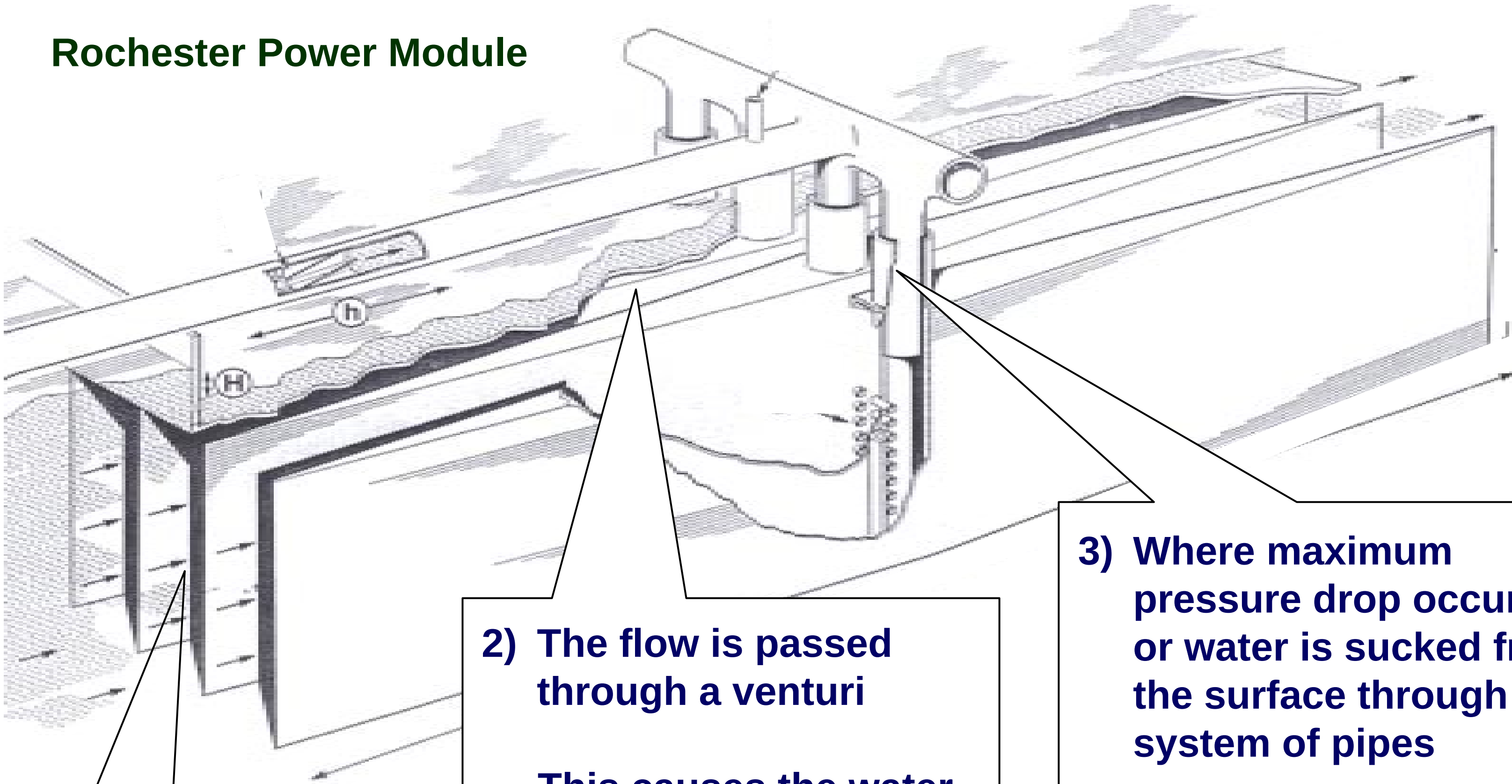


San Francisco Bay is one of top 10 tidal energy sites worldwide

- Total tidal energy in SF Bay ~ 2000 MW (> 2x peak power demand of San Francisco)
- 1 MW pilot project planned (future expansion possible)

Hydroventuri Power Module

Rochester Power Module



1) Water enters the module

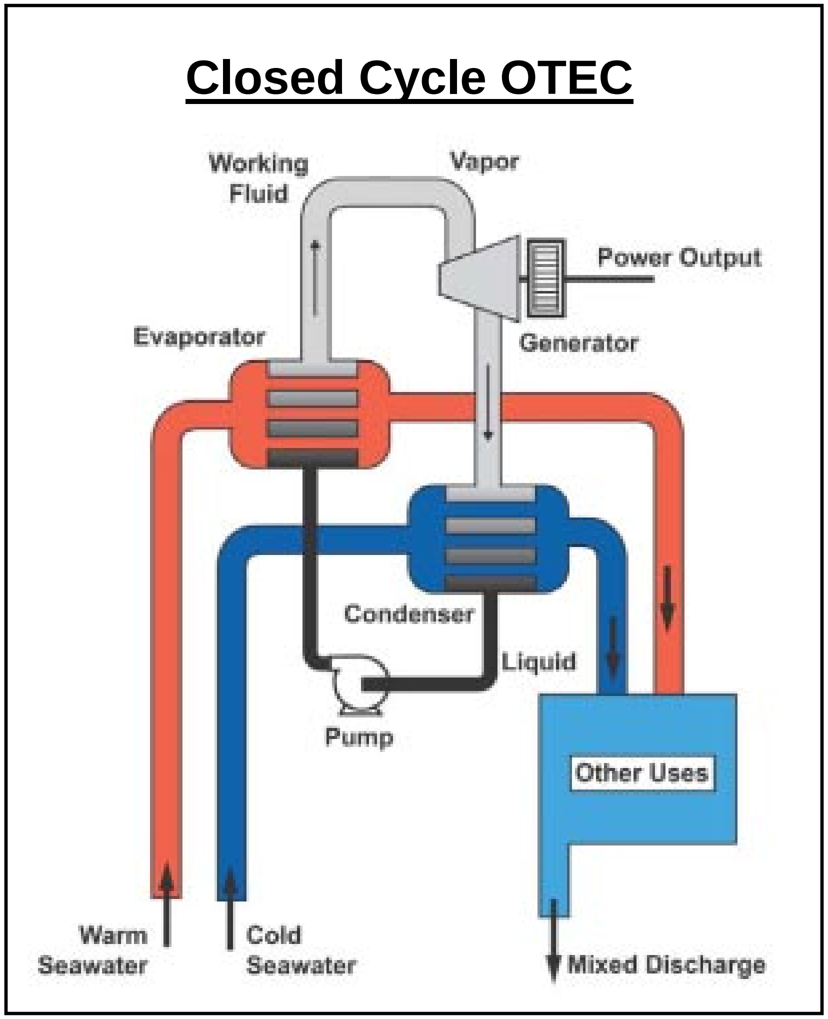
2) The flow is passed through a venturi

This causes the water to accelerate and the pressure to drop

3) Where maximum pressure drop occurs air or water is sucked from the surface through a system of pipes

The suction created in this circuit is sufficient to drive turbines

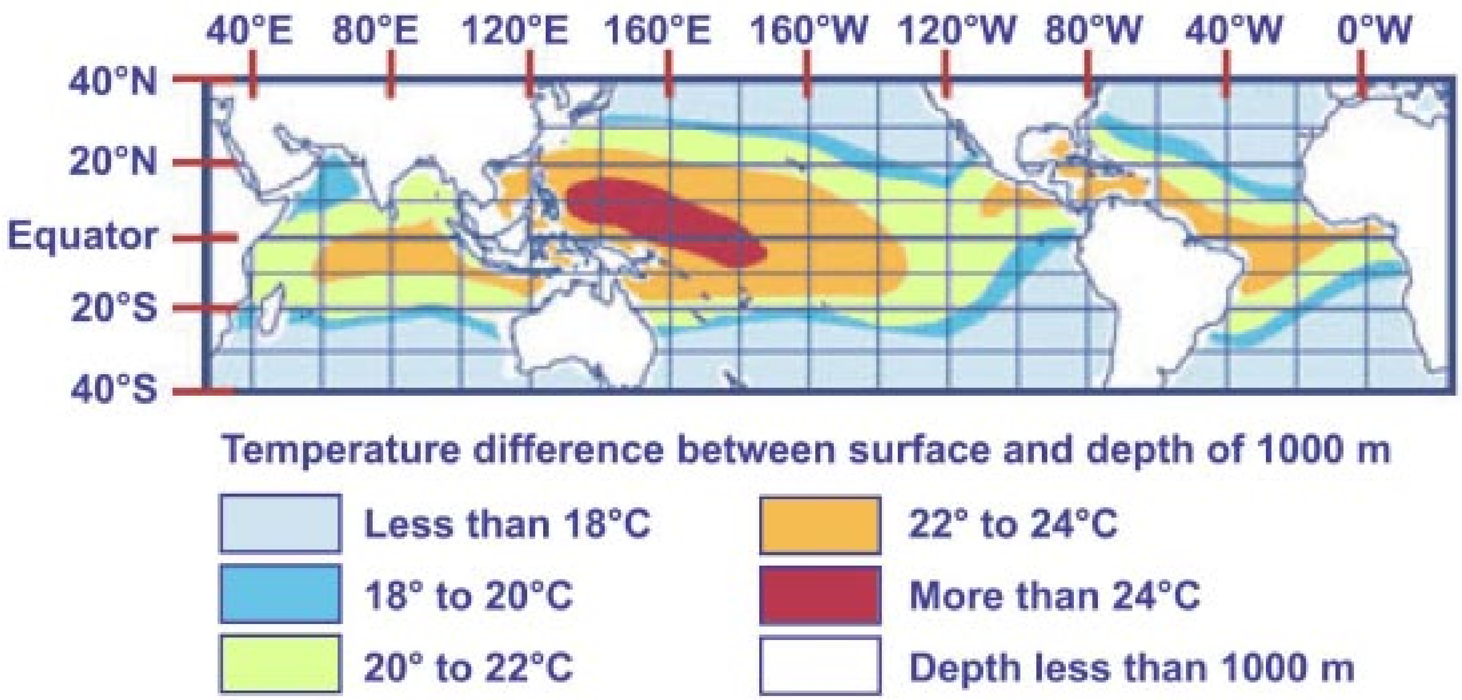
The Technologies:
Ocean Thermal Energy Conversion (OTEC)



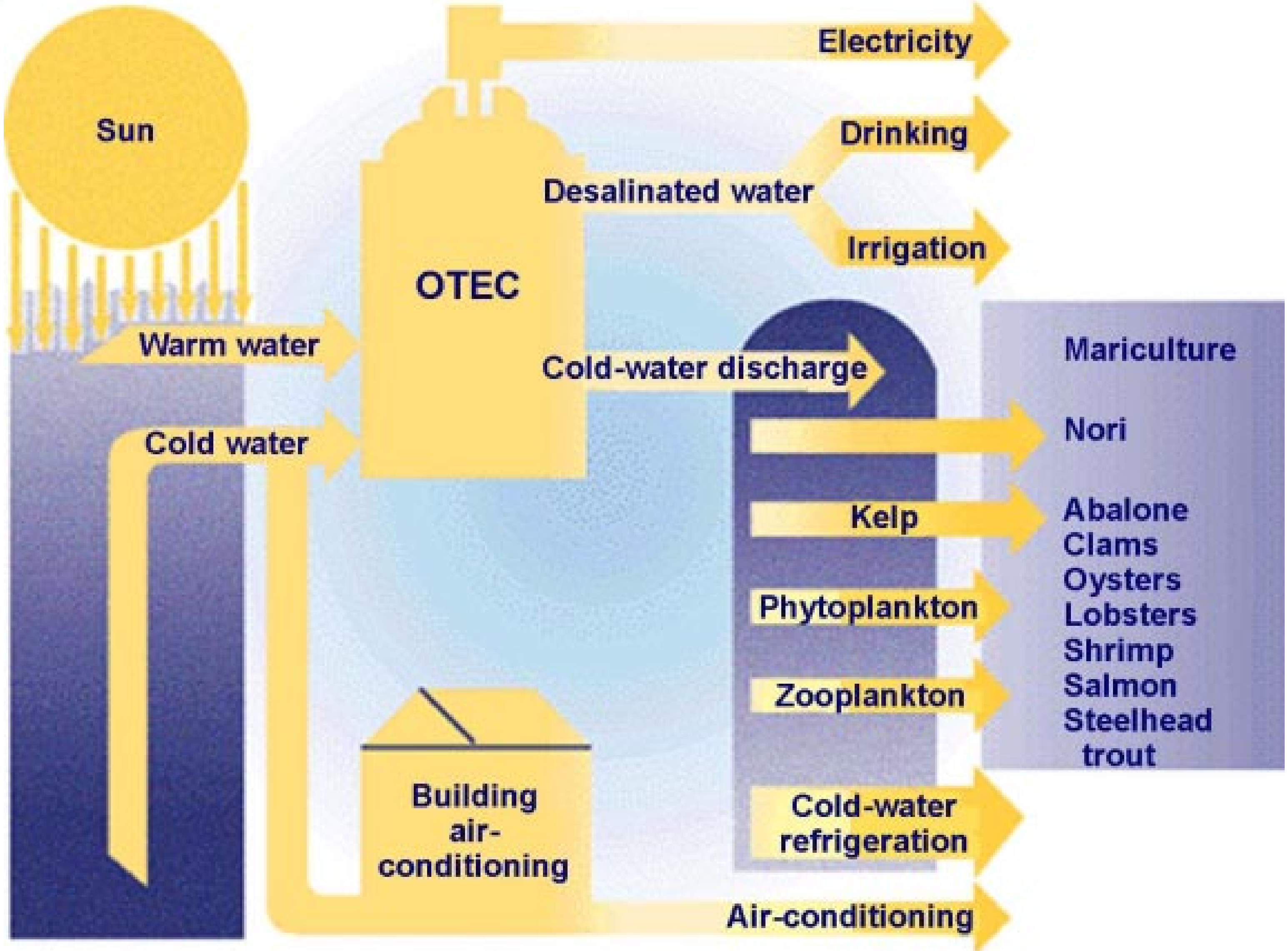
- **Ocean's natural thermal gradient (warm surface waters, cold deep waters) drives power-producing cycle**
- **OTEC converts solar radiation to electric power**
  - **Tropical seas cover 60 million km^2 -- world's largest solar collector**
  - **Solar radiation absorbed on average day equal in heat content to ~250 billion barrels of oil**
- **Three types of OTEC systems: open, closed, and hybrid**

Global Ocean Thermal Gradient

Temperature difference between warm surface water and cold deep water must be >20°C (36°F) for OTEC system to produce significant power



Other Uses for OTEC



Integration of Carbon Sequestration R&D Efforts Should Consider System Technology Platforms

- **Carbon processing (separations and capture)**
- **Biological absorption (terrestrial, oceans)**
- **Engineered injection (geological, oceans)**
- **Advanced characterization and monitoring technologies**
- **Utilization of validated modeling and simulation decision tools**

Systems Approach: 100,000-foot level

Combustion

Biological sequestration — All sources

— Oceans
  - fertilization

— Terrestrial
  - soils
  - plants
  - integrated landscape planning

Capture/separation

— Pre-combustion/direct conversion

— Post-combustion
  - solvent
  - absorbents
  - membranes

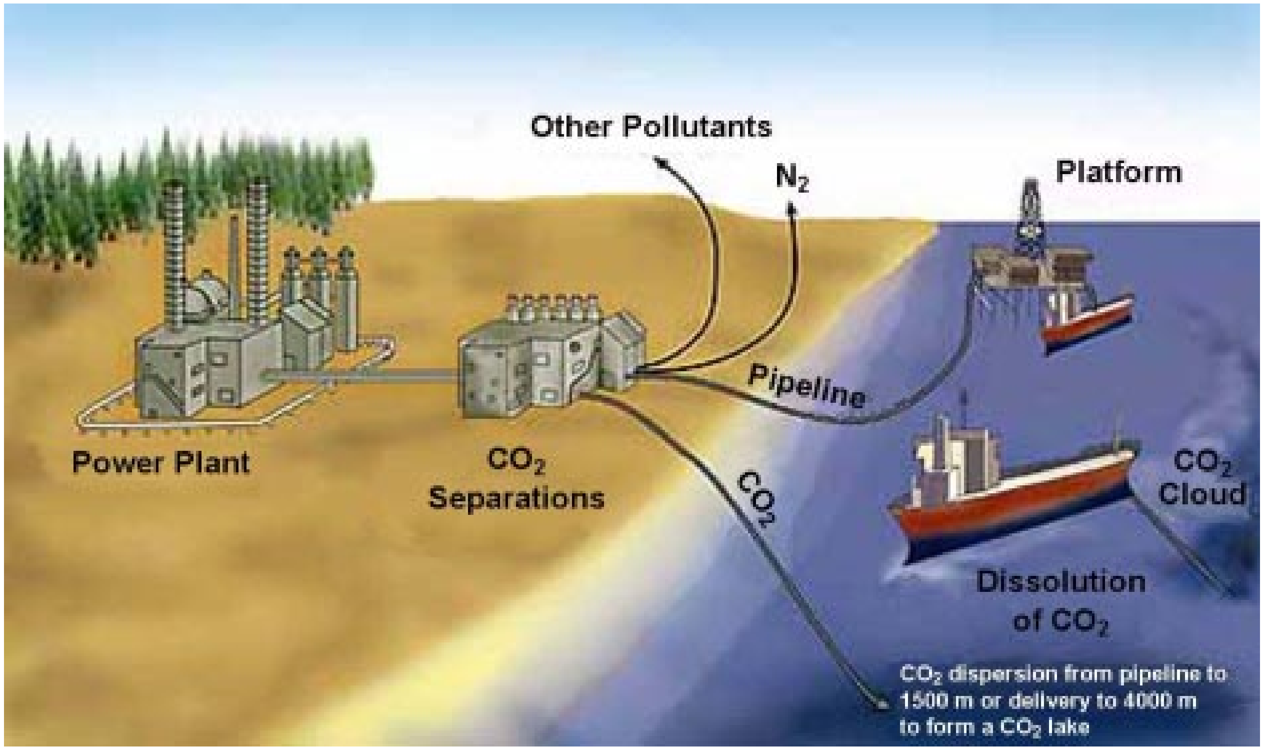
Compression/Transportation

"Fossil" sequestration — Larger point sources

— Oceans
  - direct injection

— Geology
  - oil reservoirs
  - unmineable coal beds
  - gas reservoirs
  - brine formations

Direct Injection of CO_2



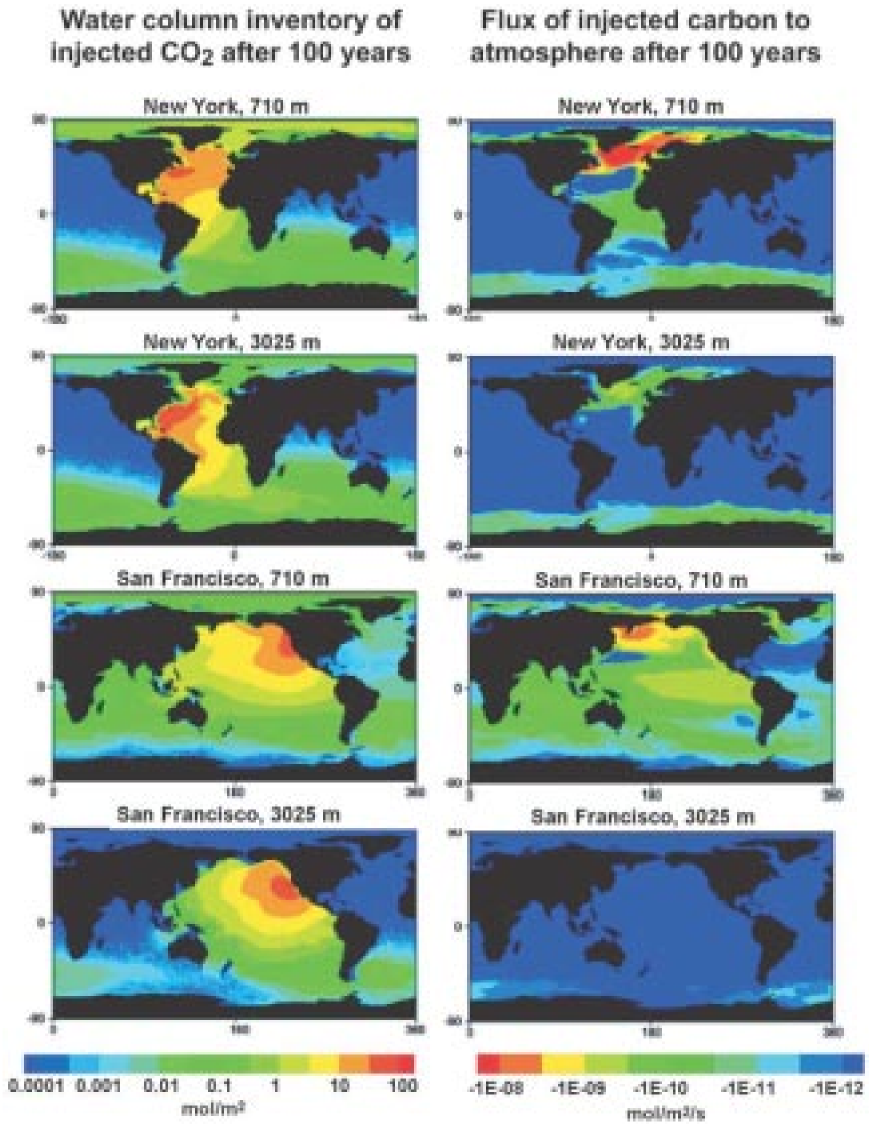
Advantages

- More localized/controllable than ocean fertilization

Disadvantages

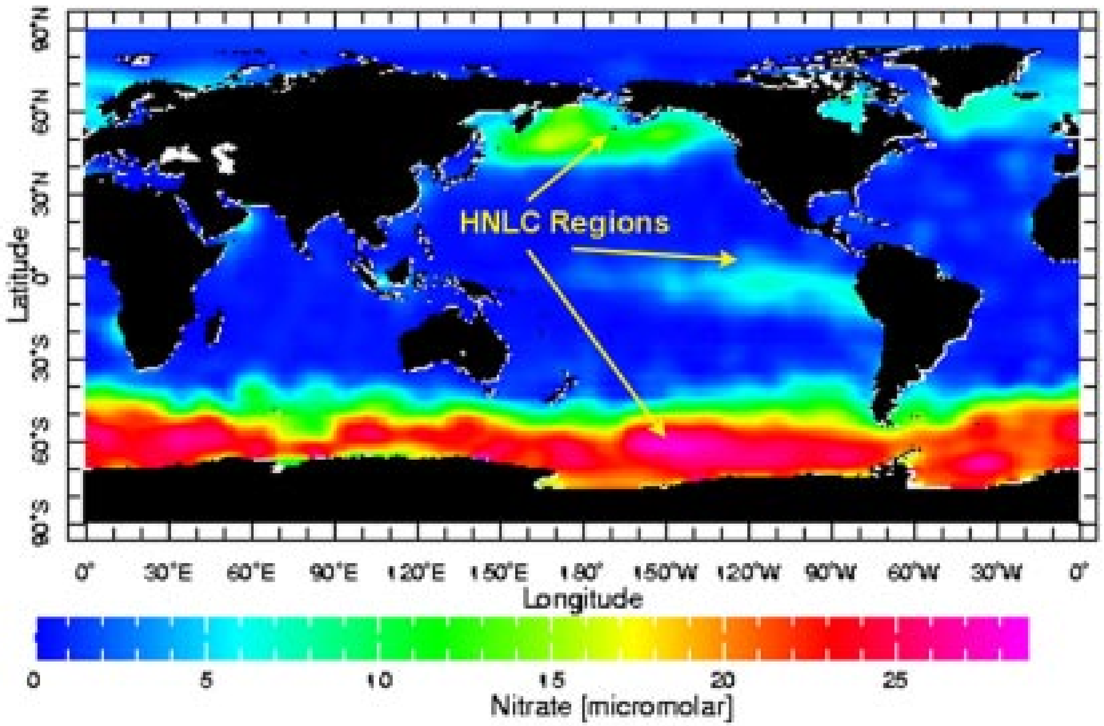
- Expensive, energy intensive
- Leakage of CO_2 over long-term?
- Environmental impacts

CO_2 Injection Model Results



Source:
Wickett et al., 2003

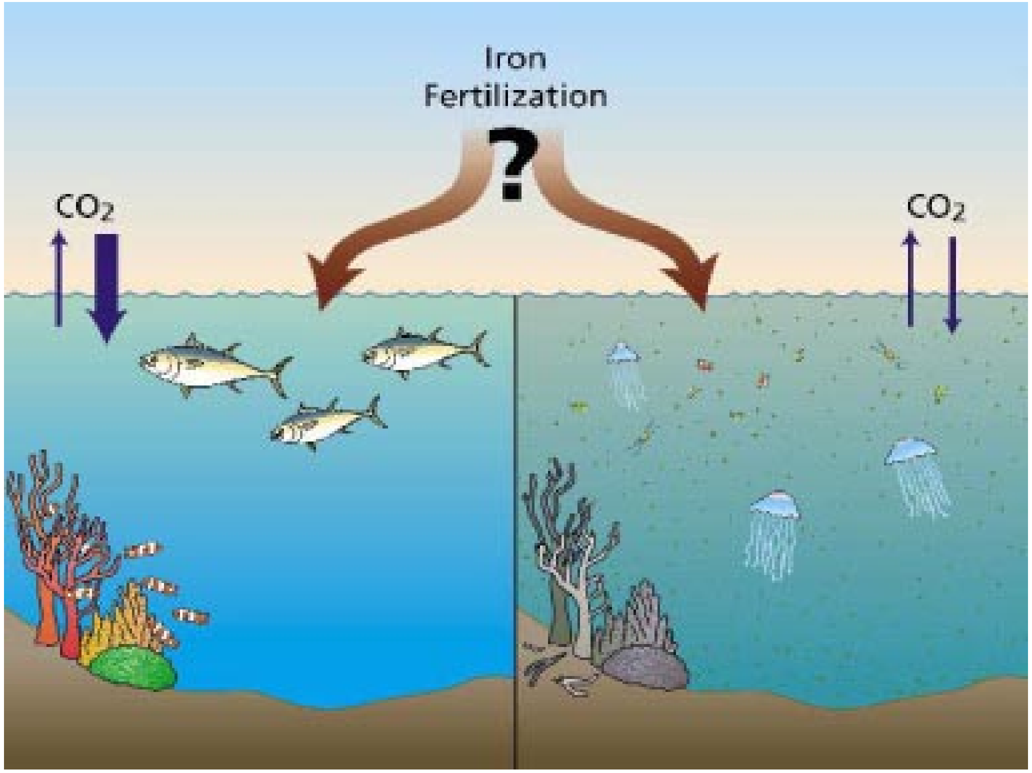
Ocean Fertilization



Hypotheses

- Phytoplankton growth in high-nutrient, low-chlorophyll (HNLC) regions limited by iron availability
- Adding iron will stimulate phytoplankton growth, increasing the "biological pumping" of carbon from surface to deep waters (i.e., sinking particles)

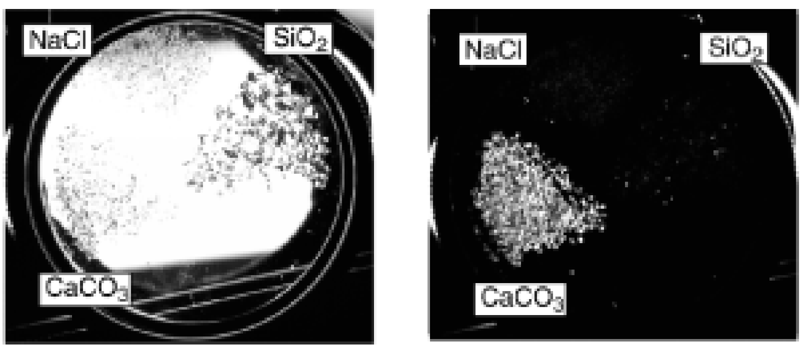
Effects of Ocean Fertilization



- **Significant CO_2 sequestration or negligible long-term removal?**
- **Enhanced fisheries or catastrophic ecosystem perturbation?**

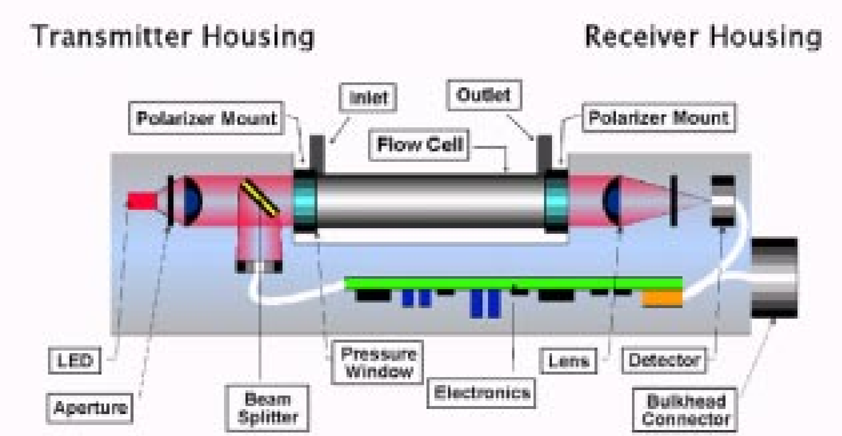
Sensor for Particulate Inorganic Carbon (PIC)

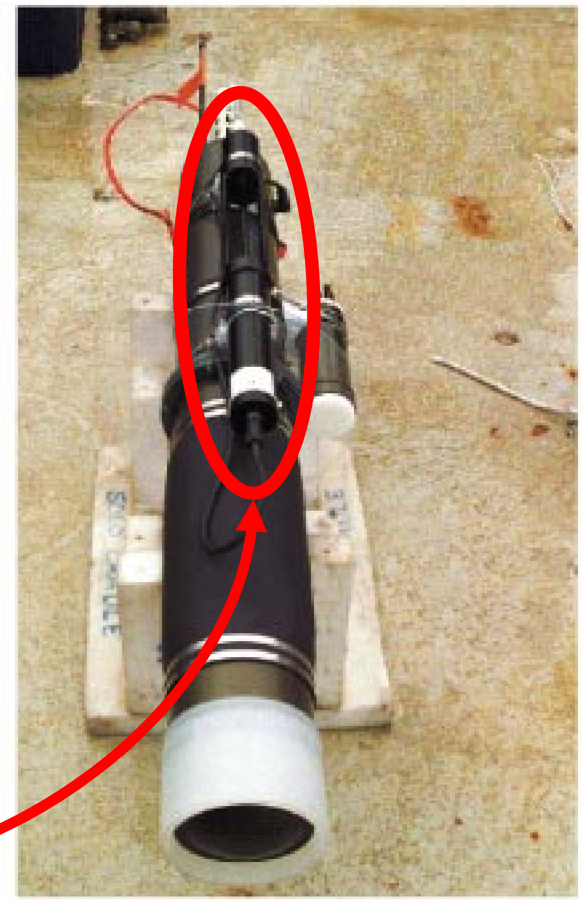
Optical Detection of PIC



Source: Guay and Bishop, 2002

In situ optical sensor for PIC



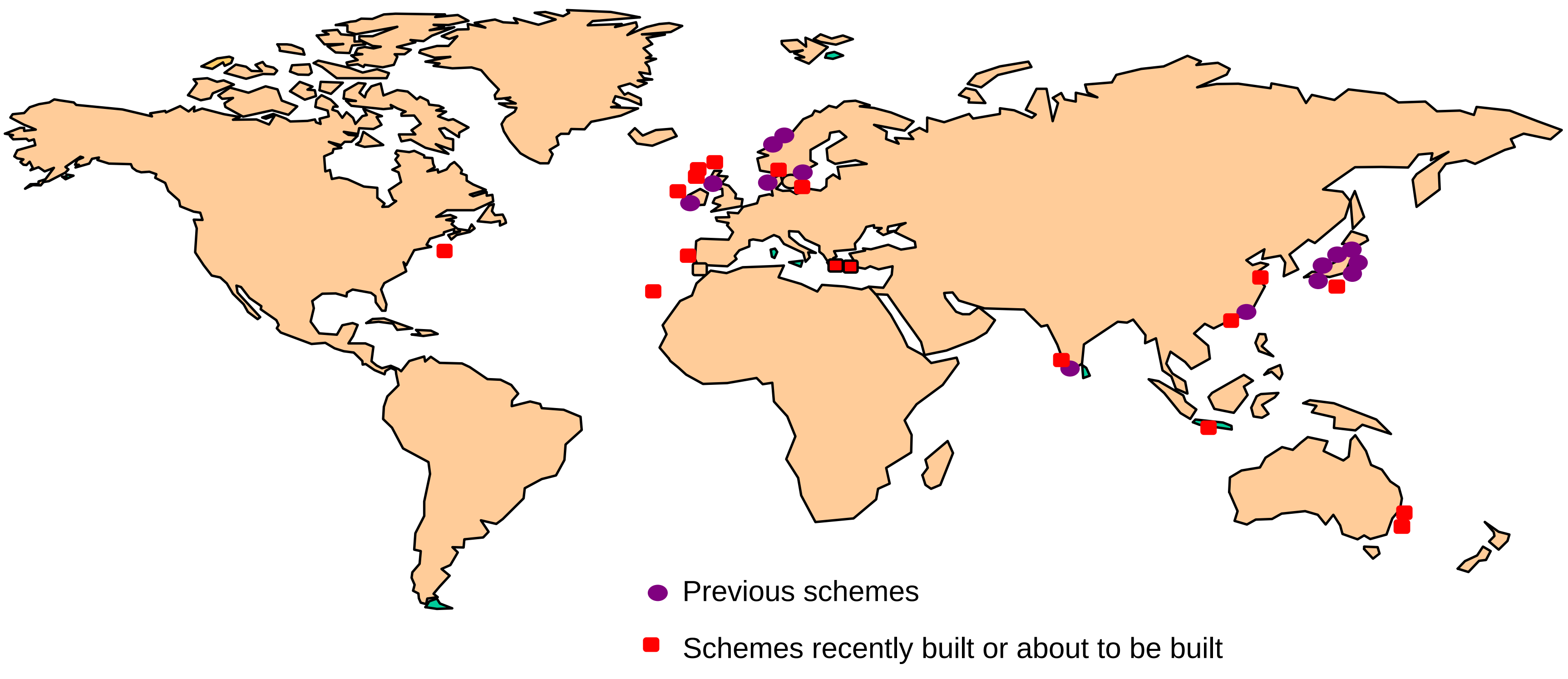


Deployment of sensor on autonomous profiling float

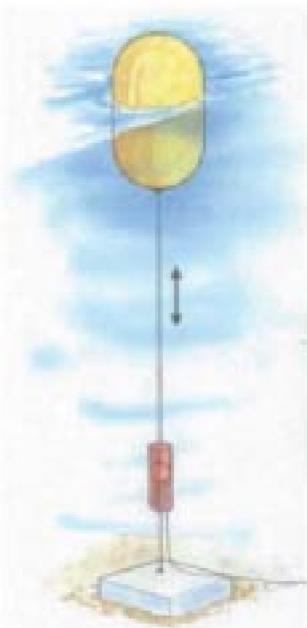
Ocean Sequestration Recommendations Merge Modeling and Experimentation

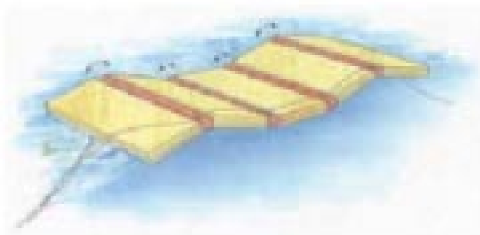
- Better understanding of ecosystem impacts associated with fertilization and direct deep injection is required
- General circulation models need improvement for better use as management and monitoring tools
- Both approaches require significant breakthroughs in cost-reduction
- Currently, technical and environmental feasibility outweighs cost issues
- Digital environmental atlas coupled to terrestrial and geologic systems

Worldwide Wave Energy Prototype Demonstration Sites



Buoyant Moored Devices



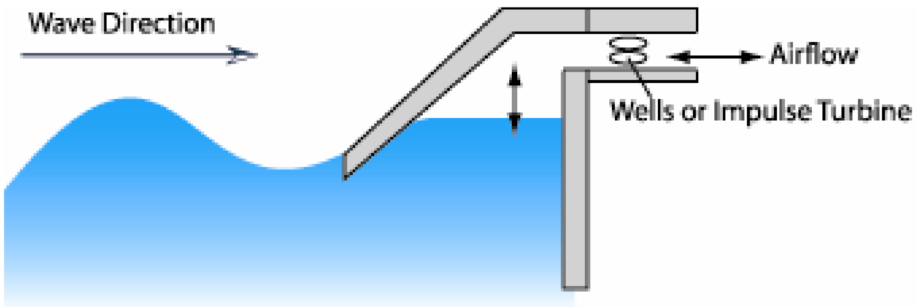


IPS Buoy Mark IV
(AquaEnergy Group Ltd, WA)

<u>Power conversion</u>:

Hydraulic compression system

Oscillating Water Column (OWC)

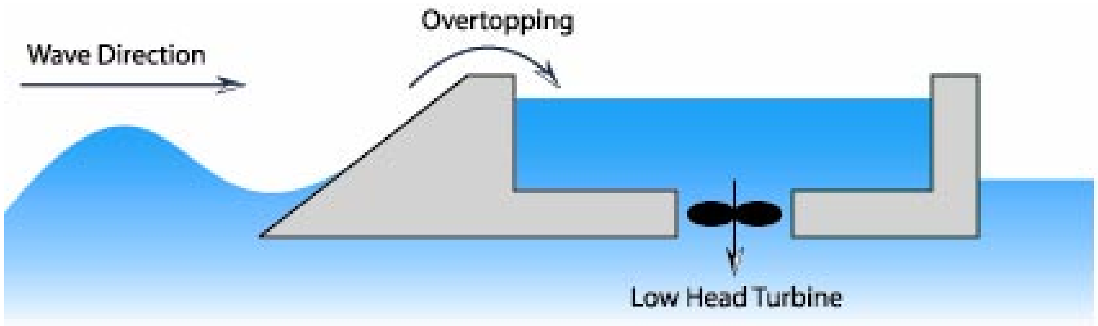


Energetech OWC
(Energetech, Australia)

<u>Power conversion</u>: Air turbine

WaveGen
Demonstration, UK

Overtopping Devices



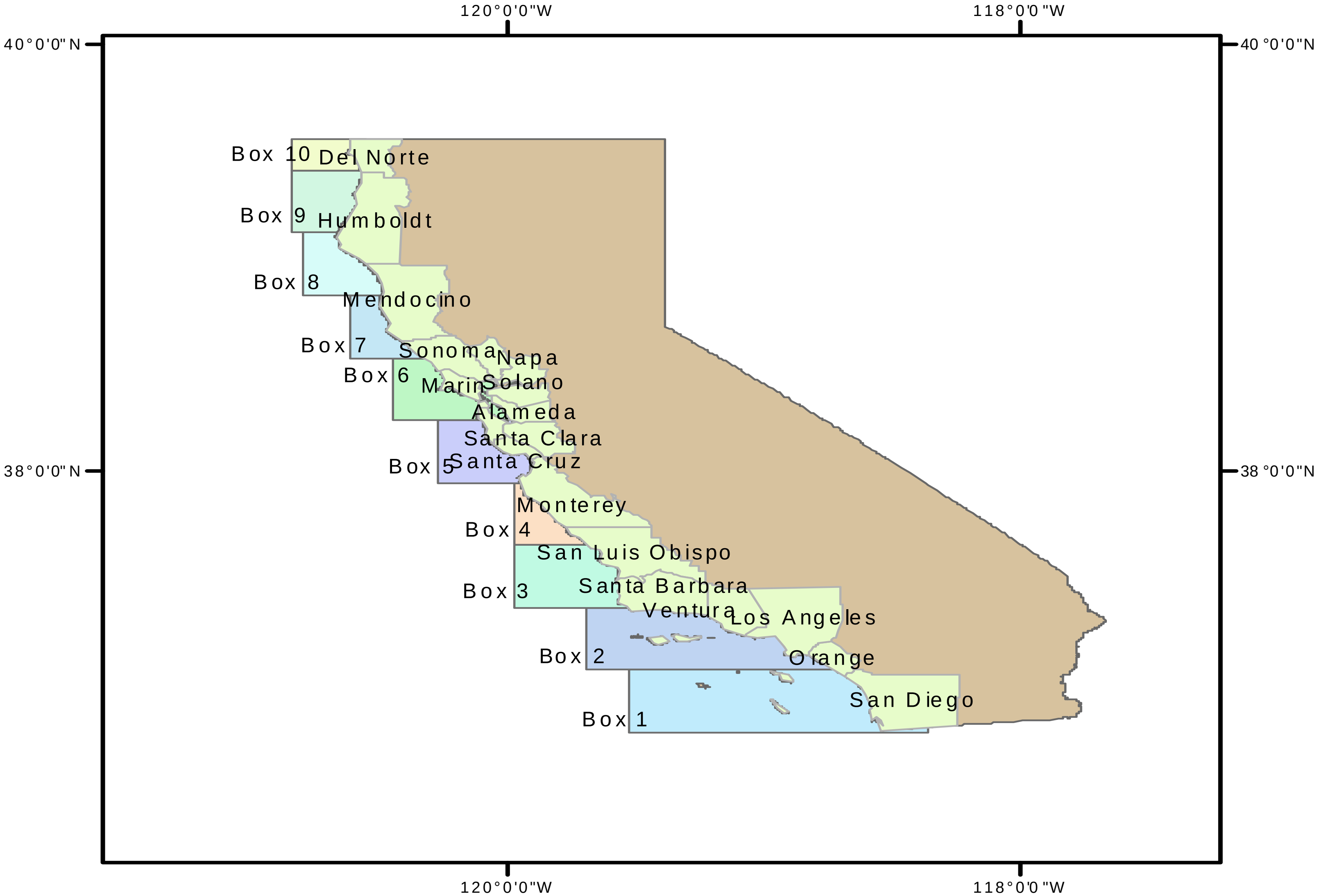
Power conversion:
Low-head water turbine

Wave Dragon (Wave Dragon International, Denmark)

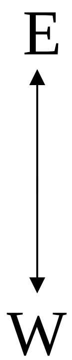
California Energy Commission
Wave Energy Resource Study

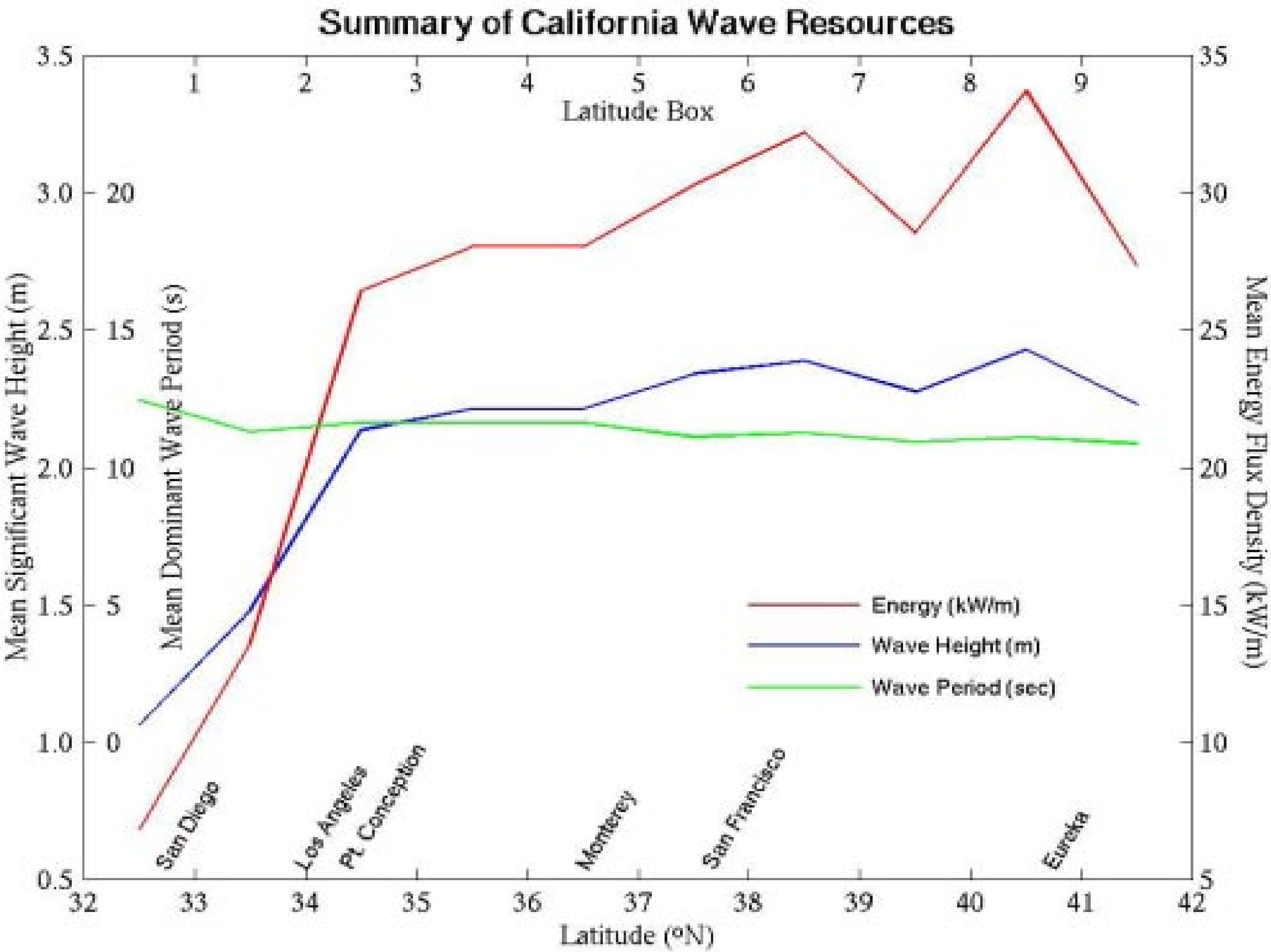
- Data sources
  - Coastal Information Data Program (CDIP), Scripps Institute of Oceanography
  - National Data Buoy Center (NDBC), NOAA
  - Wave Information Study (WIS) results
  - Pacific Ocean Reanalysis Wind 50-year time series
- Revealed:
  - CA has good wave energy resources close to shore because the ocean depth increases quickly westward
  - North of Point Conception is suited for electricity-generating WECs sited near-shore or offshore
  - South of Point Conception wave energy is dispersed because of the shadowing effect of the Channel Islands

Resource Evaluation: Ten One-Degree Latitude Cells

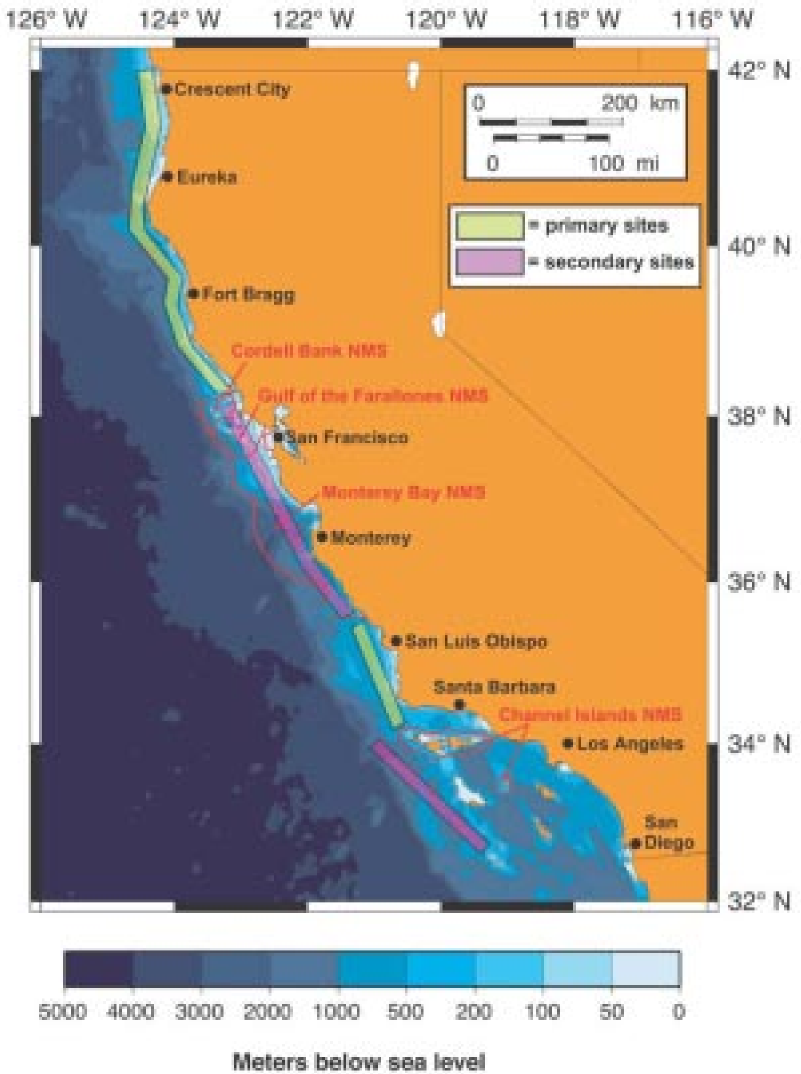


Wave Energy Density Varies Widely Off Coastline at Point Conception from N-S





California Wave Energy Resources



Primary Sites

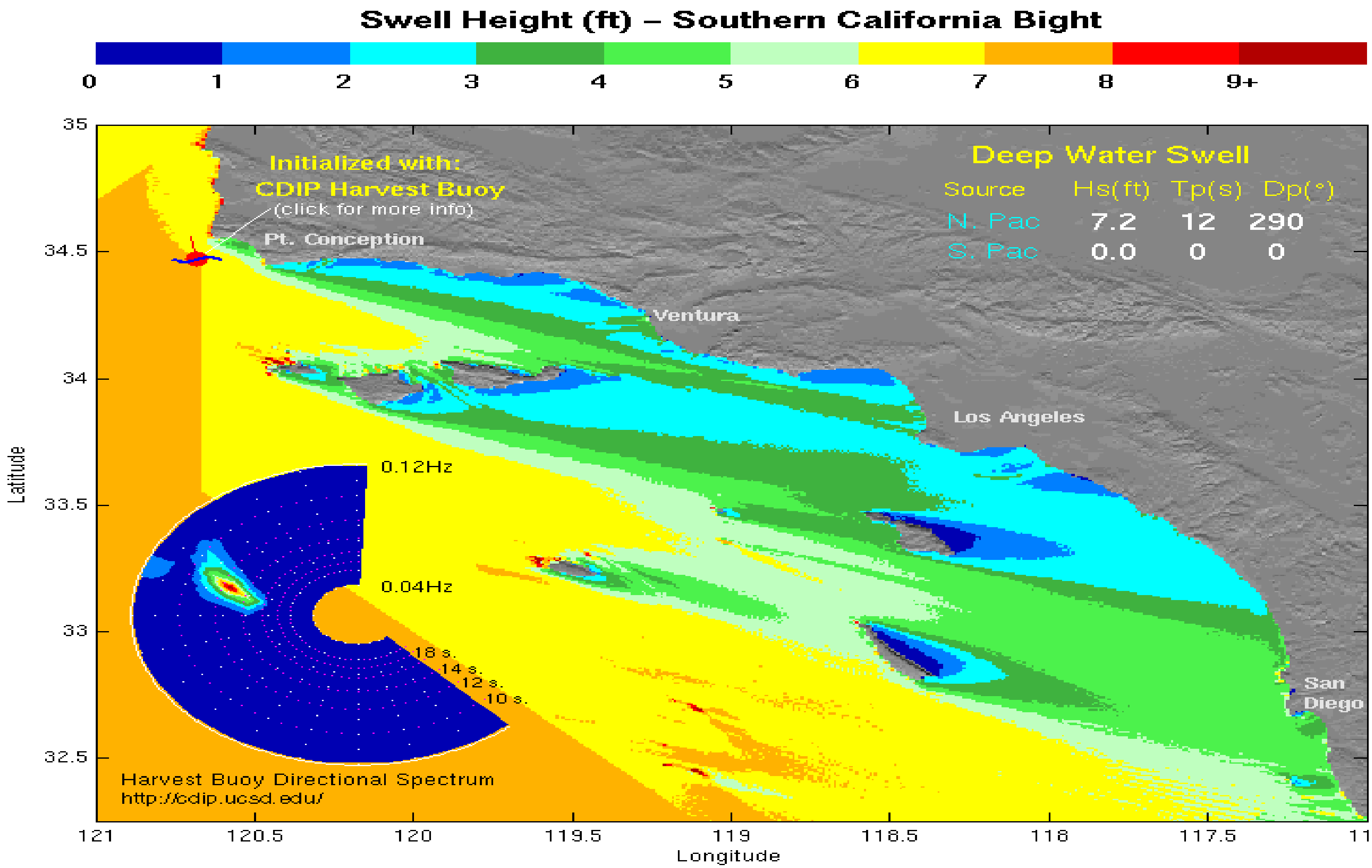
- Excellent wave conditions and deep water (> 50 m) within 10 miles from shore
- Reasonable permitting process

Secondary sites

- Sites located further offshore due to wave shadowing effects (e.g., Channel Islands in Southern California)
- Anticipated permitting difficulties (e.g., marine sanctuaries)

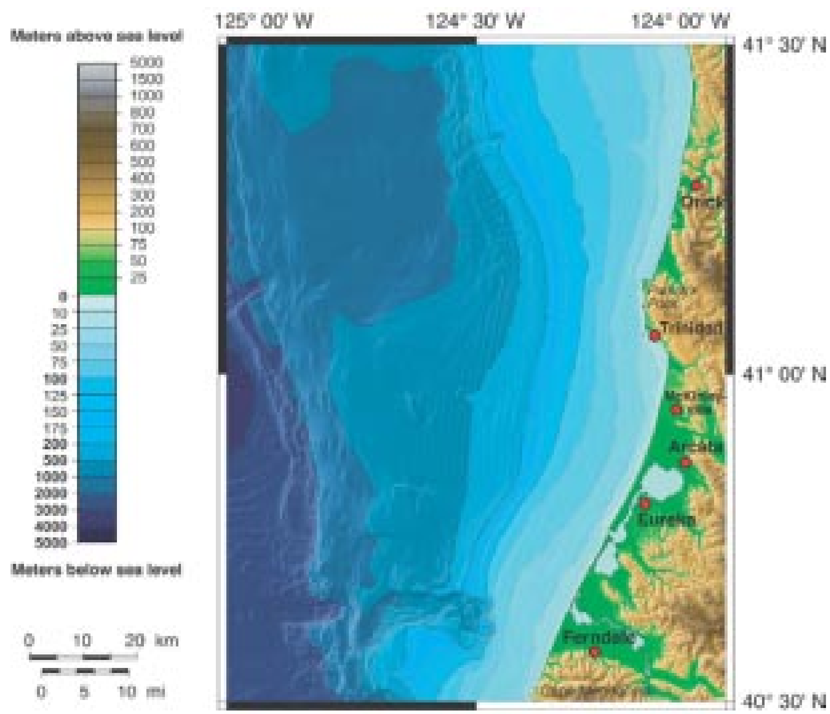
Shadowing Effects of the Channel Islands on Southern California

Analysis Time – 22 MAR 2003 : 0653 PST



Wave Statistics for Individual Cells

Cell 9: Northern Humboldt County



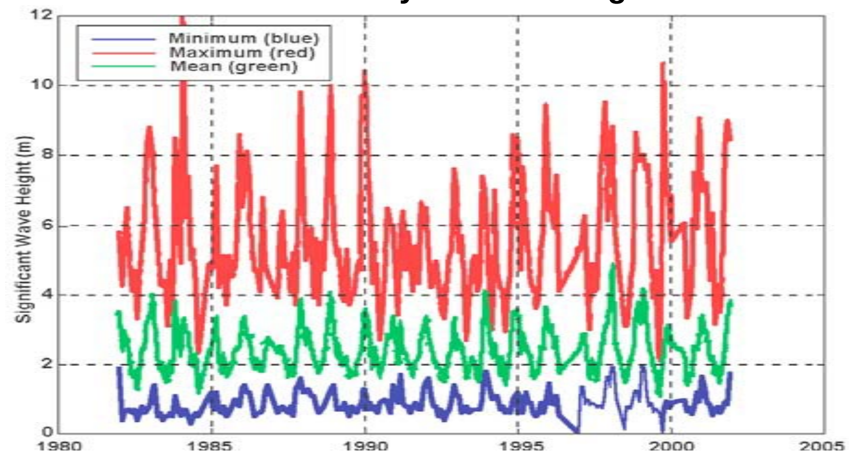
Mean Statistics

Significant wave height: 2.46 m (SD = 1.13)

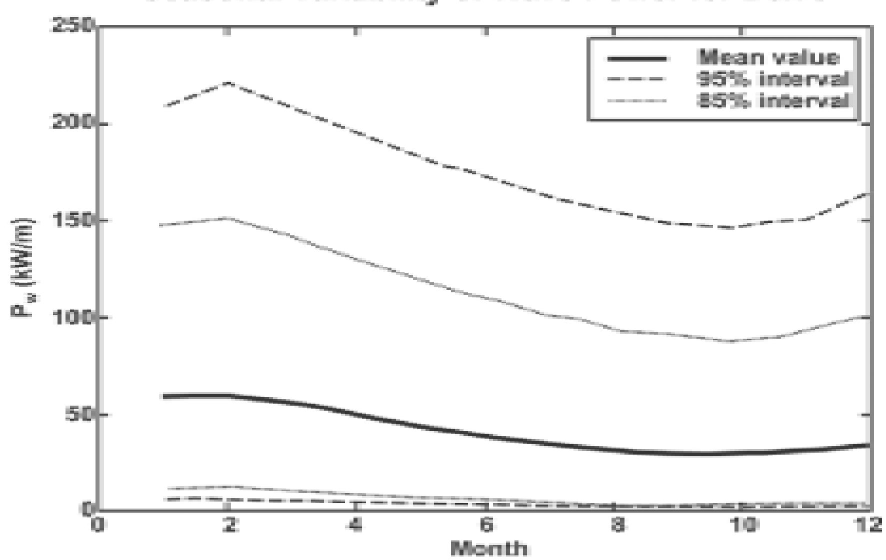
Dominant wave period: 11.14 s (SD = 3.41)

Wave power density: 33.71 kW/m

Interannual Variability of Wave Height for Box 9



Seasonal Variability of Wave Power for Box 9



Projected Costs of Produced Electricity are Highly Uncertain

- Very little short-term operational experience available
- Wave energy conversion technologies are in the development and testing stage
- Offshore is much more expensive than onshore
- Economic improvements likely to result from
  - Increased capacity factors based on improved tuning algorithms
  - Improved reliability and resulting lower O&M costs
  - Improved maintenance strategies
  - Standards for operation and maintenance should lower insurance cost
  - Economies of scale and learning by doing

Environmental and Permitting Issues

Environmental Impacts Must Be Better Characterized

Activities affiliated with WEC

- Directional drilling through shoreline
- Laying/burying power transmission cables
- Setting down anchors on seabed
- Drilling into seabed for heavy-uplift anchors
- Operation and maintenance activities
- Attenuation of wave energy during power generation

Potential impacts

- Visual impacts in scenic areas
- Disruption of fish and marine mammal migration
- Perturbation of sedimentation patterns
- Disturbance of seabed ecosystem
- Navigation hazards

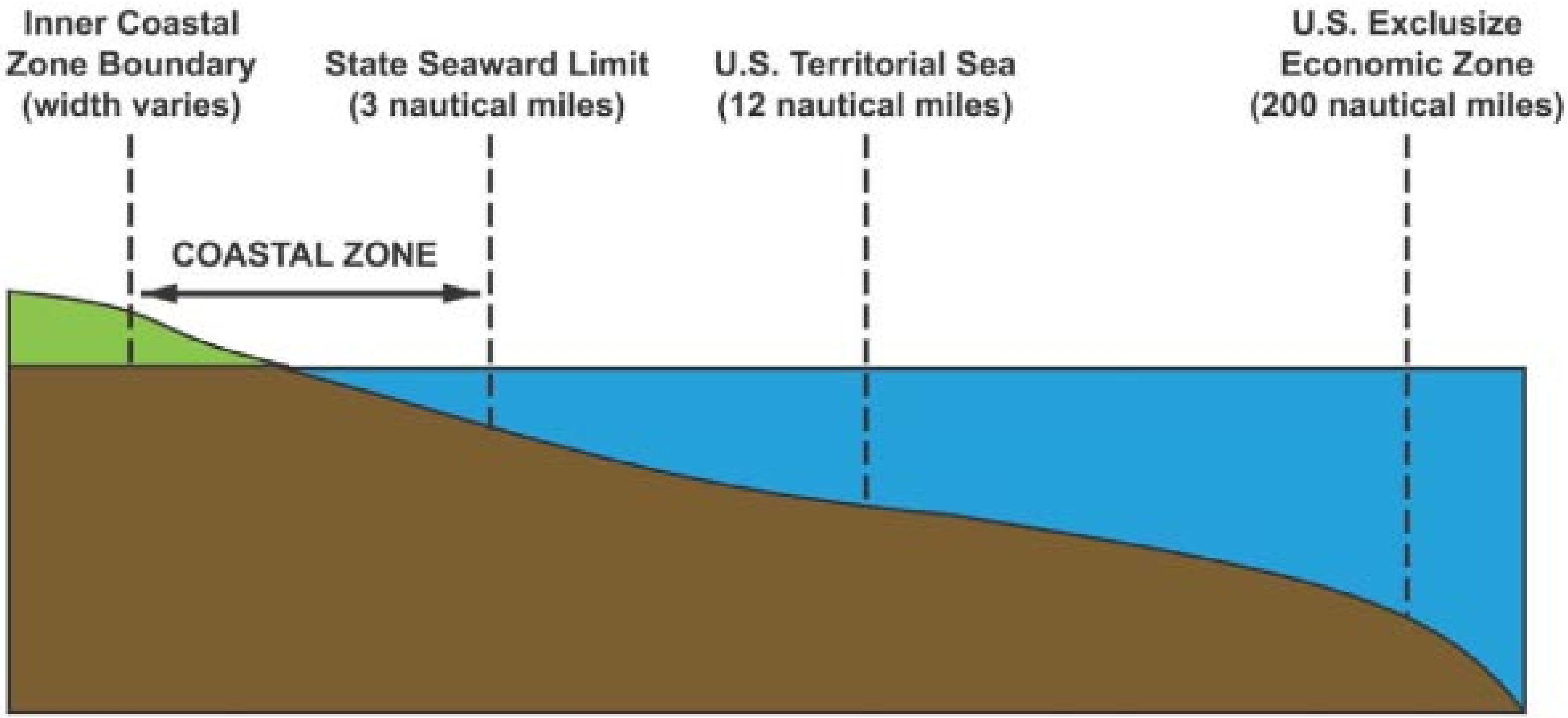
Environmental Impacts

Hypothesis: WEC power generation has low environmental impact relative to other renewable and fossil energy sources

- Most significant impacts occur during construction/installation (i.e., short-lived)
- Low visual impact for low-lying, offshore devices
- No major disturbances anticipated to fish and marine mammal migrations
- No emissions and/or discharges

Maritime Boundaries

Coastal development involves federal, state and local jurisdictions



Permitting: Relevant Agencies

Federal

- U.S. Army Corps of Engineers (USACE)
- U.S. Coast Guard
- U.S. Environmental Protection Agency (EPA)
- Federal Energy Regulatory Commission (FERC)
- U.S. Fish and Wildlife Service
- National Marine Fisheries Service

State

- California Coastal Commission
- California State Lands Commission
- California State Water Resources Control Board
- Regional Water Quality Control Boards
- California Department of Fish and Game

** Local county/city government agencies may also be involved

Permitting: Relevant Regulations

Federal

- River and Harbors Act
- Title 33 -- Navigation and Navigable Waters
- Clean Water Act
- Marine Protection, Research and Sanctuaries Act
- Federal Power Act
- Coastal Zone Management Act
- Submerged Lands Act
- Endangered Species Act
- Fish and Wildlife Coordination Act
- National Environmental Policy Act (NEPA)

State

- Porter-Cologne Water Quality Control Act
- California Coastal Act
- California State Lands Act
- California Endangered Species Act
- California Environmental Quality Act (CEQA)

Summary of Wave Report Conclusions

Benefits

- Nearshore wave power sites could provide California with an additional 8000 MW capacity, doubling the currently installed renewable generation
- The long-term deep-water potential can exceed the nearshore potential by a factor of 5-10, assuming it proves technically and economically feasible (expected within 10 years)
- Wave energy conversion (WEC) devices are deployed in locations that are currently under-utilized
- WEC devices are low-lying deployed 3-10 miles off shore -- low visual impact
- Anticipated environmental impacts are minimal and can be mitigated where applicable using an appropriate regulatory framework

Risks

- Cost competitiveness of ocean wave power conversion remains to be proven, especially as it pertains to O&M costs
- The current permitting framework in California may be a key issue in establishing commercial wave farms -- resulting development timeframes might prove prove too long and too costly for private industry
- There are considerable technical risks associated with the operation of in-ocean systems, and the survivability of devices operating in this harsh environment will still need to be proven
- WEC devices are in an immature stage of development

Some Closing Thoughts On Ocean Energy Potential and Issues

- The potential for oceans as an energy resource cannot be ignored
- Considerable national and international funding will be required to prove economics
- CEC/PIER has limited resources
  - Can partner with USG
  - Must focus on near-term projects
- Energy Innovation Small Grants Program is an avenue for small projects
  - Need better internal focus
  - Current, on hold, project will be recommended

Driving to a Sustainable Future: The “E”s are Linked

- Environment
- Energy
- Economics
- Equity
- Education